



# **EDGEWOOD**

## **CHEMICAL BIOLOGICAL CENTER**

U.S. ARMY RESEARCH, DEVELOPMENT AND ENGINEERING COMMAND

**ECBC-TR-365**

### **TEST RESULTS OF CHEMICOVER DRESS LEVEL B SUIT TO CHALLENGE BY CHEMICAL AND BIOLOGICAL WARFARE AGENTS AND SIMULANTS**

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## EXECUTIVE SUMMARY

As part of the Domestic Preparedness Program, one Occupational Safety and Health Level B\* suit design was tested to assess its capability to protect in a chemical warfare (CW) agent or biological agent environment. Swatches of material from the ChemiCover Dress suit were tested for resistance to permeation for sarin (GB) and mustard (HD). From that data, the authors calculated the estimated time it would take for sufficient agent to permeate the suit to cause physiological effects in a person wearing the suit. The suit was also tested for its protection factor in an aerosol environment (aerosolized corn oil, which may be representative of a chemical or biological agent, was used). Protection factor is defined as the ratio between the challenge concentration outside the suit and the measured concentration inside the suit. The tests are described, and the calculated physiologically-derived breakthrough times and protection factors are presented.

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\* Level B protection consists of chemical-resistant clothing (overalls and long-sleeved jacket; hooded one or two piece chemical splash suit; disposable chemical-resistant one-piece suit), inner and outer gloves, chemical-resistant safety boots and hard hat with pressure-demand full-facepiece SCBA or pressure-demand supplied-air respirator with escape SCBA. Level B, rather than Level A, protection is used when a high level of respiratory protection is required but less skin protection is needed.

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## **PREFACE**

The work described in this report was authorized under the Expert Assistance (Equipment Test) Program for the U.S. Army Edgewood Chemical Biological Center (ECBC) Homeland Defense Business Unit. The work started in February 2001 and was completed in January 2002.

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# TEST RESULTS OF CHEMICOVER DRESS LEVEL B SUIT TO CHALLENGE BY CHEMICAL AND BIOLOGICAL WARFARE AGENTS AND SIMULANTS

## 1. INTRODUCTION

In 1996, Congress passed Public Law 104-201 (Defense Against Weapons of Mass Destruction Act of 1996), directing the Department of Defense (DoD) to assist other federal, state, and local agencies in enhancing preparedness for terrorist attacks using weapons of mass destruction. The DoD responded by forming the Domestic Preparedness Program that same year. One of the objectives of the Domestic Preparedness Program was to enhance emergency and hazardous material response to nuclear, biological and chemical (NBC) terrorism incidents. As part of an effective response, people who are responding to an incident will use personal protective equipment to protect them from exposure to chemical agents or biological agents. The specific personal protective equipment (PPE) that will be used depends upon the situation that they encounter and what they have on hand. In some cases, Level B protective suits may be required to enter a contaminated or potentially contaminated area. Level B suits are chemical-resistant clothing that protects the wearer from liquid chemicals. Air is supplied by a pressure-demand full-facepiece self-contained breathing apparatus (SCBA) or pressure-demand supplied-air respirator with escape SCBA.

## 2. OBJECTIVES

This study evaluated one common and commercially available Level B suit. The ChemiCover Dress suit met the Occupational Safety and Health Administration (OSHA) description of Level B as defined in 29 Code of Federal Regulations (CFR) 1910.120, Appendix B. This suit was evaluated to assess how well it resisted vapor permeation from liquid contamination<sup>1</sup> by chemical agents Sarin (GB) and mustard (HD) and droplet penetration by a corn-oil aerosol from 0.4 to 5 microns in diameter (used to simulate the 0.4 to 0.6 micron military standard for the possible biological or chemical particulate threat). This information is intended for emergency responders as an aid in evaluating Level B suits when they choose to include military chemical and biological agent protection as a criterion. The information supplements data and information provided by the suits' manufacturers. The suit was tested in new, as-received condition. The effects of aging, temperature extremes, laundering, and other factors are beyond the intended scope of this test program. These tests were conducted to assess percutaneous protection<sup>2</sup> only.

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<sup>1</sup> Throughout this report, the term permeation is used even though for some of the tests the precise mechanism of agent transfer is not determined, and penetration is likely to be involved also.

<sup>2</sup> Inhalation and ocular protection are typically provided by the use of either a SCBA or air-supplied respirator that covers the eyes, nose and mouth.

### 3. TESTING AND DATA ANALYSIS

#### 3.1 Testing Overview.

The ChemiCover Dress suit was manufactured by New Pac Safety AB (Habo, Sweden) and was a clear plastic. The model number was C/19R and the article number was 2010. Figure 1 is a digital photograph of the suit label. Tests included the measurement of permeation of both GB and HD through material swatches. Tests were also conducted to measure the total aerosol leakage into the suits through seams, seals, etc. when worn as part of a complete PPE system.



**Figure 1. ChemiCover Dress Label**

#### 3.2 Liquid Challenge/Vapor Permeation Testing (Agent Swatch Testing).

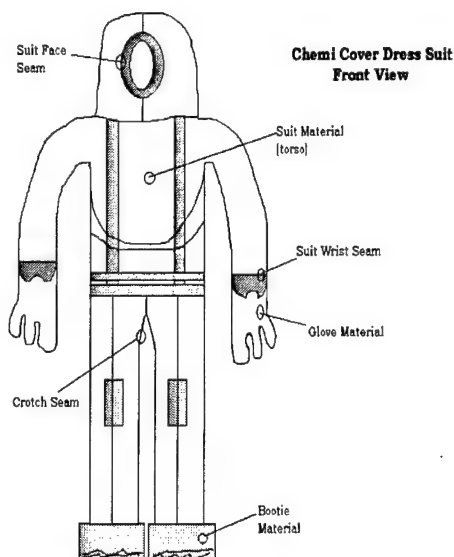
##### 3.2.1 Liquid Challenge/Vapor Permeation Testing Procedures.

This testing was conducted to measure the actual permeation of chemical agents GB and HD through suit swatches over a 24-hr period. The test was intended to assess how well the suit materials and seams resist agent permeation. The amount of agent applied and duration of exposure do not represent any particular threat that responders may encounter, but they do serve as a common point of reference for all test results. The testing was performed by the Applied Chemistry Team, Research and Technology Directorate, Edgewood Chemical Biological Center (ECBC).

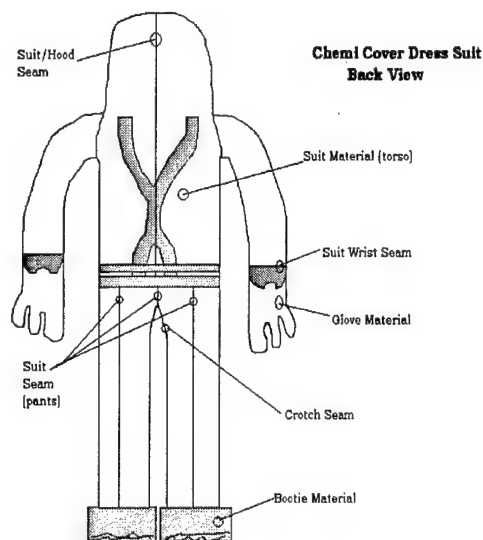
##### 3.2.1.1 Swatch Preparation.

The suit was stored at the ECBC Mask Issue Point and was delivered by Mask Issue personnel just prior to testing. The suit was kept in the laboratory during testing and was laid flat on a laboratory table for storage.

The swatch locations to be sampled were given in the PPE Test Team Work Contract for Level A Ensembles (written communication, R. Belmonte, Engineering Directorate, ECBC, 25 June 1997). These sampling locations were listed as suit material (SM), suit seam (SS), visor material (VM), zipper/suit material seam (ZP), glove (GL) and visor material/suit material seam (SV). The ChemiCover Dress suit did not have a visor or a zipper but had booties and a hood. The management decision was made to take swatches from the SM (torso), GL, SS (pants), suit/hood seam (HS), bootie material (BM), suit/wrist seam (SW) and suit/face seam (SF). Swatches were taken from both SW and SF areas to generate a sufficient number of swatches. Sketches of the areas sampled are given in Figures 2 and 3. The swatches were normally cut the day before testing on a sample press and conditioned overnight at the test temperature. The swatch diameter was 1 and 15/16 in. Normally the swatches would be mounted in test cells that were then placed in the test cabinet for conditioning.



**Figure 2. Swatch Sampling Locations – Front**



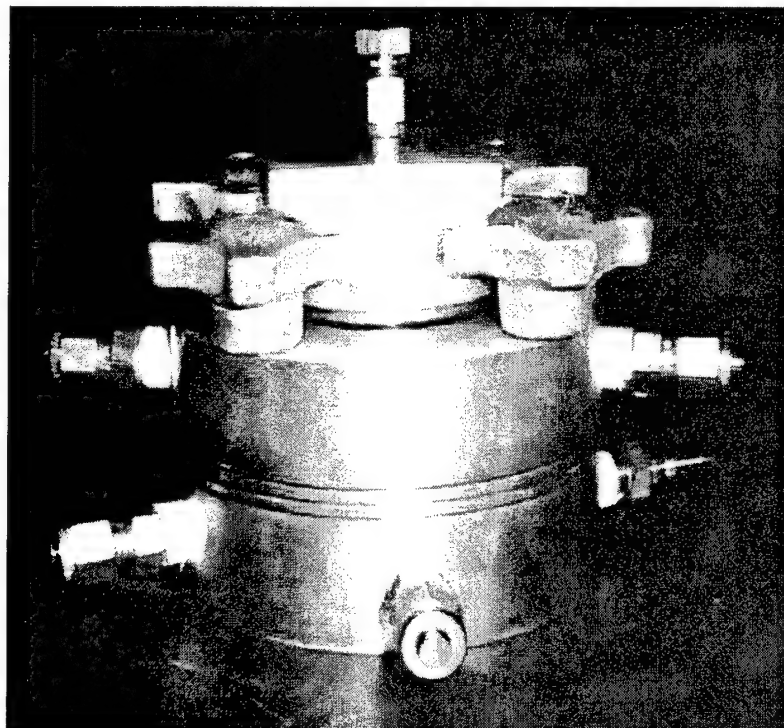
**Figure 3. Swatch Sampling Locations – Back**

### 3.2.1.2 Test Procedure.

The test methodology was taken from TOP 8-2-501<sup>3</sup> and is described in Appendix A. Three swatches were taken from each of seven different areas (described above) of the suit

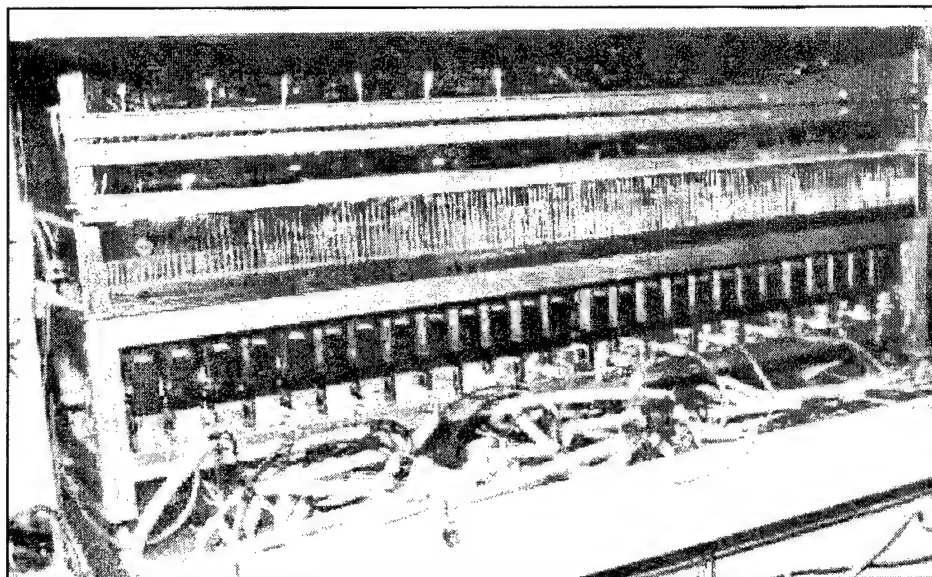
<sup>3</sup> Test Operations Procedure (TOP) 8-2-501, Permeation and Penetration of Air-Permeable, Semipermeable and Impermeable Materials with Chemical Agents or Simulants (Swatch Testing). U.S. Army Dugway Proving Ground, UT 3 March 1997, UNCLASSIFIED Report (AD A322329).

18 total swatches for GB and 18 more for HD. Swatches were taken from 80-mil silicone rubber (M45 mask formulation) slabs<sup>4</sup>. For each test nine test swatches, one negative control swatch (suit material) and one silicone swatch were placed in test cells (one swatch per test cell). Figure 4 is a digital photograph of the test cell used. Laboratory personnel applied a predetermined liquid agent challenge ( $10 \text{ g/m}^2$ ) to the top surface of each swatch. Agent droplets were applied to the surface of the first swatch at time zero. Agent was then applied to the surface of each succeeding swatch at roughly 1-min intervals. The upper chamber of each test cell was sealed. The test cell was then placed into a TOP permeation test apparatus with system control and data acquisition system, fabricated by Battelle Memorial Institute (Columbus, Ohio). A digital photo of the permeation apparatus is shown in Figure 5. The test cell inlet was connected to the manifold from which clean air at the test conditions was drawn. The test cell outlet was connected to the vacuum source whose flow rate was metered by a mass flow controller. Thus a 1.0 L/min flow of air was maintained in the lower test cell chamber beneath each swatch.



**Figure 4. TOP Permeation Cell**

<sup>4</sup> Originally, it was intended to use silicone swatches as references or controls, but it was soon found that permeation through the silicone varies too widely for it to be used for that purpose. Silicone swatches were used anyway, because they serve as a reliable source of agent vapor to assure the tester that the MINICAMS™ is responding properly during tests when little or no agent permeates the actual test swatches.

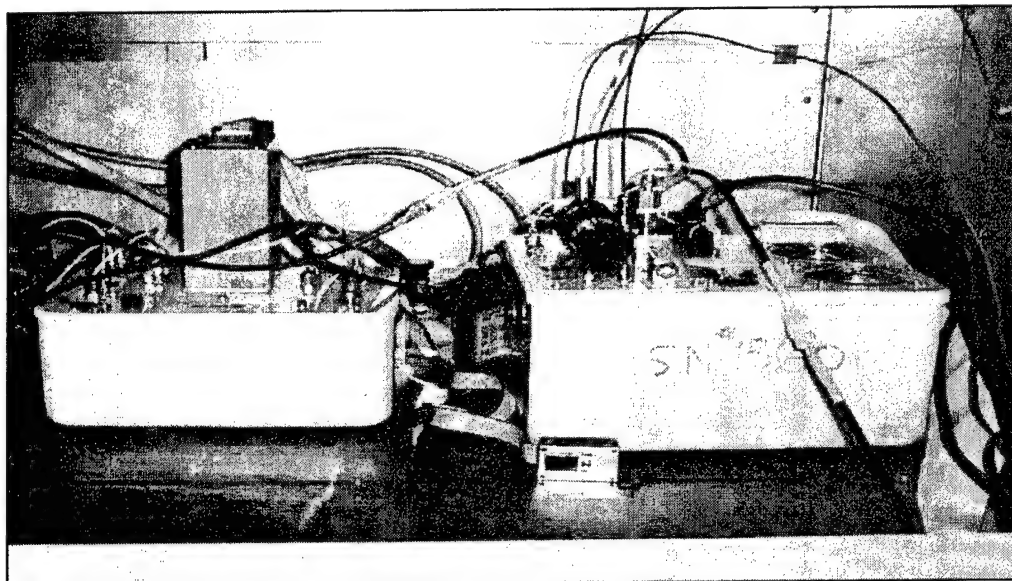


**Figure 5. TOP Permeation Apparatus**

During the 24-hr test period, gas samples were taken on a sequential basis by a laboratory MINICAMS™ (OI Analytical, CMS Field Products Group, Birmingham, AL) with stream selection system (a miniaturized gas chromatograph with flame photometric detector and sampling system) from the airstream beneath each swatch. The MINICAMS™ is illustrated in Figure 6. Gas sampling by the MINICAMS™ began for the first swatch approximately 10 min following agent application. Subsequent 3-min cycles of the MINICAMS™ were composed of 2 min of desorption of collected agent vapor from the pre-concentrator tube (PCT) onto the GC column followed by 1 min of gas sampling (collection of agent vapor in the PCT). Sampling was done sequentially through the negative control swatch, nine swatches (three from one sampling area, three from a second sampling area and three from a third sampling area) and the silicone swatch. A clean air gas sample was taken between each swatch gas sample and at least 3 clean air gas samples were taken after the silicone swatch to purge the MINICAMS™ sampling path. The sampling sequence was then repeated. The negative control swatch, nine swatches and the silicone swatch were sampled approximately every 60 min.

The MINICAMS™ first determined the amount of agent vapor in each gas sample. Using this result, the amount (ng) of agent vapor present in the airstream that passed beneath the swatch over the time from the previous gas sample to the current gas sample was determined by the MINICAMS™ permeation software. This amount of agent vapor was presumed to be the amount of agent vapor that permeated the swatch over that time interval. Given the area of the test swatch, the MINICAMS™ permeation software determined the  $M_f$  at each elapsed time for each swatch where the cumulative mass of agent permeating the swatch per unit area at any elapsed time during the 24-hr test was defined as  $M_f$ . Over the 24-hr test period, a series of  $M_f$  values was calculated for each swatch.





**Figure 6. MINICAMS™ and Stream Selection System**

### 3.2.2 Liquid Challenge/Vapor Permeation Testing Analysis.

The suit yielded  $M_f$  data for 18 swatches for each of the two agents over the 24-hr test period. The  $M_f$  data were taken for each of the three swatches from one sampling area tested with one of the agents. For this report, the average (of three swatches) cumulative permeation ( $M_f$ ) for each suit area (for example, gloves) was calculated. This average was then presented, at each of the reported elapsed times, as representative of the suit's permeation resistance at that sampling area. The reported elapsed time for each sampling area was the sum of the elapsed times for the three swatches divided by three. For each suit tested, swatches were taken from a single suit.

To estimate  $M_f$  at each elapsed time for a suit, the simplifying assumption was that the exposure was uniform over the entire suit. This permitted the use of the weighting factor scheme developed by Belmonte<sup>5</sup> to determine the weighted average  $M_f$  over the entire suit at each average elapsed time. The average elapsed time was the sum of the reported elapsed times for all the sampling areas divided by the number of sampling areas. The weighting factors were assigned roughly on the basis of surface area assigning a minimum assigned value of 5%. The weighted average  $M_f$  at any average elapsed time was calculated using the following equation:

$$\begin{aligned} \text{Weighted average } M_f = & 0.6(\text{suit torso material } M_f) + 0.1(\text{glove material } M_f) \\ & + 0.1(\text{suit pants seam } M_f) + 0.05(\text{suit/hood seam } M_f) \\ & + 0.1(\text{bootie material } M_f) + 0.05(\text{suit/face seam } M_f). \end{aligned}$$

<sup>5</sup> Belmonte, R.B., *Test Results of Level A Suits to Challenge by Chemical and Biological Warfare Agents and Simulants: Summary Report*, ERDEC-TR-513, U.S. Army Edgewood Research, Development and Engineering Center, Aberdeen Proving Ground, MD, August 1998, UNCLASSIFIED Report (AD A353013).



### 3.2.3 Relationship Between Liquid Challenge/Vapor Permeation Test Results and Skin Exposure.

The permeation test was designed to distinguish among these material swatches according to their permeation resistance to chemical agents. It was not intended to specifically replicate threat scenarios that may be encountered in actual use or to determine safe wear times. As previously reported by Belmonte<sup>5</sup>, it was instructive to estimate the agent dosage ( $C_{it,skin}$ ) that would result from such a standard agent challenge as a relative indication of possible physiological effects. This was done by converting the weighted average  $M_f$ s to equivalent agent dosages. This relationship was developed by Fedele (written communication, Dr. P. Fedele, R&T Directorate, ERDEC, July 1997) and was reported by Belmonte<sup>5</sup>. For suit materials impermeable to airflow, the equation was:

$$\text{Agent Dosage (mg-min/m}^3\text{)} = \frac{M_f \text{ (ng/cm}^2\text{)}}{P_s, \text{ Permeability of skin to agent vapor (cm/min)}}$$

where skin permeability ( $P_s$ ) was 2 cm/min for HD and 0.1 cm/min for GB. The agent dosage could then be compared to doses that are known to cause certain levels of toxicity. Skin permeability was assumed to be constant over all regions of the body.

### 3.2.4 Evaluation Criteria for Liquid Challenge/Vapor Permeation Test Results.

When analyzing the test results, it was useful to determine whether the data indicated that the suit provided percutaneous (i.e., skin) protection over some period of time. Mustard vapor can produce erythema (reddening of the skin, certain body regions) at dosages of approximately 100 mg-min/m<sup>3</sup>, and can produce vesication (skin burns and blisters, certain body regions) at 200 mg-min/m<sup>3</sup>. Sarin vapor can produce incapacitation (twitching, convulsions or loss of consciousness) at unprotected, percutaneous dosages of approximately 8000 mg-min/m<sup>3</sup> and can be lethal at unprotected, percutaneous dosages of 15000 mg-min/m<sup>3</sup> where exposed persons are healthy, young, fit, and well-nourished males of approximately 70-kg mass. People who are smaller, less fit, etc., may exhibit adverse effects at lower doses ( $C_{it,skin}$ ). The conservative simplifying assumption was that the suit was exposed to a uniform liquid GB challenge over its entire surface, resulting in a uniform exposure of all body regions to GB vapor. This is conservative because the areas likely to receive more exposure (hands, arms, chest, back) would also be those less sensitive. Therefore, the amount of agent per unit area (weighted average  $M_f$ ) necessary to permeate the suit to produce a predetermined physiological effect was estimated by using each of the above dosages and the appropriate skin permeability ( $P_s$ ). These values were used in the graphs of weighted average  $M_f$  versus time given in Appendix C and summarized in Table 1. The breakthrough dosages were assumed to be the HD dosage that produced erythema (100 mg-min/m<sup>3</sup>) and the GB dosage that produced incapacitation (8000 mg-min/m<sup>3</sup>). A physiologically derived breakthrough time was the time when the weighted average  $M_f$  equals the breakthrough  $M_f$  criterion.

**Table 1. Agent Breakthrough Criteria**

Agent	Breakthrough Dosage (mg-min/m <sup>3</sup> )	Physiological Effect	Skin Permeability (P <sub>s</sub> ), (cm/min)	Breakthrough M <sub>f</sub> , (ng/cm <sup>2</sup> )*
HD	100	Erythema	2	200
HD	200	Vesication	2	400
GB	8000	Incapacitation	0.1	800
GB	15000	Lethality	0.1	1500

\* These breakthrough criteria are not to be construed as safe threshold values; they are being used only to rank suits.

### 3.3 System Test (Aerosol Simulant).

#### 3.3.1 Aerosol Simulant Test Procedures.

The testing was conducted to determine leakage of a challenge corn-oil aerosol (physical simulant of a biological or chemical agent aerosol) into a suit ensemble while people of different sizes were wearing appropriately sized ensembles. Volunteers dressed in Level B suits with SCBA entered a chamber with aerosol simulant and performed a standardized series of exercises. Instrumentation measured any aerosol leakage (presumed to be penetration) into the suit through gaps between ensemble components. During the test, the people in the suits performed standardized movements. A brief description of the test and movements made by the people during the test are given in Appendix B. Eight suits were worn by 12 volunteers on each of two days (not necessarily the same 12 on both days), for a total of 24 trials. However, because it was not possible to retain the same 12 volunteers throughout the entire course of testing, this variable (the differences among wearers) was not held constant.

From this test a protection factor (PF) was derived. In simplest terms, PF is a measure of the challenge concentration outside the suit divided by the concentration inside the suit ensemble. For example, if the concentration of aerosol inside the suit ensemble was found to be 1/10th the value of the average concentration outside the suit ensemble, the PF is equal to 10.

#### 3.3.2 Aerosol Simulant Analysis.

Samples of aerosol were taken continuously at the neck area and upper arm within the suit and their concentrations were measured by laser photometry, recorded in a computer file and displayed continuously on a computer monitor. These sampling locations were selected as being the most likely locations for aerosol leakage to occur (Leakage usually occurs near openings such as the neck, visor, zipper or outlet valve openings). This was thought to be the worst case and the PF is a worst case PF.

The PF data were presented based upon predetermined PF pass levels, ranging from 2 to 100,000 (i.e., at each pass level the number of failing and passing suits was recorded). The higher the percentage of test occasions that passed at a given PF, the greater the probability that the suit will provide that level of protection in use.

## 3.4

Results and Discussion.

The HD weighted average  $M_f$  data are presented in Table C-7 and the GB weighted average  $M_f$  data are presented in Table C-8. The aerosol simulant results are presented in Table C-9. The HD individual swatch data are given in Tables C-2 through C-3 and the GB individual swatch data are given in Tables C-4 through C-6. The plot of the weighted average HD permeation is shown in Figure C-3 and the plot of weighted average GB permeation is shown in Figure C-4. The plot of HD permeation by sampling area is shown in Figure C-5 and the plot of GB permeation by sampling area is shown in Figure C-6. The results are summarized in Table 2.

**Table 2. Overall Test Results**

Breakthrough Time (min)		Aerosol PF Pass Rate (%) at PF* Equal to:			Exercise Phase
Incapacitation	Erythema				
GB	HD	0	10	20	
		100	3.1	0	Pre-Operational
121	38	Not Tested	Not Tested	Not Tested	Operational

\* These breakthrough criteria are not to be construed as safe threshold values; they are being used only to rank suits.

The MINICAMS™ minimum detection limit for HD was 1.0 ng for all tests and the detection limit for GB was 0.4 ng for all tests. There were no visible effects on any of the materials from either HD or GB exposure.

Thickness measurements of all swatches tested were taken just prior to testing. At least five measurements were taken on each swatch using an Ames dial comparator (B. C. Ames Company, Waltham, MA). For each swatch, the thicknesses were averaged. The average thicknesses are given in Table C-1.

## 4. CONCLUSIONS AND RECOMMENDATIONS

The test data reveals that the ChemiCover suit tested can protect the wearers from liquid CW agents but that the suit only provides minimal protection from a vapor or aerosol threat. Breakthrough times should not be interpreted as the time that a suit can be safely worn, either for HD or GB. Breakthrough times should only be used to compare suit materials. In other words, the suit material does provide limited skin protection, but the suit itself provides little or no skin protection.

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## ACRONYMS AND ABBREVIATIONS

BM	Bootie material
CFR	Code of Federal Regulations
Ct	Vapor exposure, product of vapor concentration (mg/m <sup>3</sup> ) and time (min)
C <sub>It,skin</sub>	Vapor exposure to skin
cm <sup>2</sup>	Square centimeters
CW	Chemical warfare
°F	Temperature in degrees Fahrenheit
delta p	Differential pressure
DoD	Department of Defense
ECBC	U.S. Army Edgewood Chemical Biological Center
ERDEC	U.S. Army Edgewood Research, Development and Engineering Center
g	Gram
GB	Sarin, Isopropylmethylphosphonofluoridate
GC	Gas chromatograph
GL	Glove
HD	Sulfur Mustard; 2,2'-Dichlorodiethylsulfide
hr	Hour
HS	Suit/hood seam
in	Inch
kg	Kilograms
L	Liter
M <sub>f</sub>	Cumulative mass permeation through the fabric
m <sup>2</sup>	Square meters
m <sup>3</sup>	Cubic meters
mg	Milligram
min	Minute
μL	Microliter
ng	Nanogram
NBC	Nuclear, Biological and Chemical
ND	Non-detectable
NR	Not Reported
OSHA	Occupational Safety and Health Administration
PCT	Pre-concentrator tube
PF	Protection Factor
PPE	Personal Protective Equipment
P <sub>s</sub>	Skin permeability
RH	Relative Humidity
SCBA	Self-Contained Breathing Apparatus
SF	Suit/face seam
SM	Suit Material
SS	Suit Seam

SV	Visor materials/suit material seam
SW	Suit/wrist seam
TOP	Test Operations Procedure
VM	Visor Material
ZP	Zipper/suit material seam

## APPENDIX A

### MODIFIED STATIC DIFFUSION TEST PROCEDURE

#### Modified Static Diffusion Test

This test procedure was adapted from Test Operations Procedure (TOP) 8-2-501, Permeation and Penetration of Air-Permeable, Semipermeable and Impermeable Materials with Chemical Agents or Simulants (Swatch Testing). U.S. Army Dugway Proving Ground, UT, 3 March 1997, UNCLASSIFIED Report (AD A322329). The test procedure was entitled "Semipermeable and Impermeable Materials Static Diffusion Penetration Testing (Liquid Agent Challenge/Vapor Penetration;  $\Delta p = 0$ , Single Flow Test)". The following procedure was used:

1. Upon receipt of a suit, all available information concerning the suit will be recorded; date of manufacture, lot number, serial number, materials of construction, etc.
2. From each suit, three each 1 and 15/16-in diameter material swatches will be taken for mustard (HD) and a like number taken for sarin (GB). Depending upon the suit configuration, 3 seam swatches (same diameter) will be taken plus triplicate swatches of other flat components such as visor, gloves, suit/visor interface and zipper/material interface for HD and an equal number for GB. Each swatch will be placed in an airtight bag and given a unique serial number, which will be placed on the bag. A list of serial numbers will be kept with the swatches. Alternatively, the swatches for each day's test will be cut from the suit and placed in the environmental chamber for conditioning. Sample identification will accompany each swatch.
3. The test apparatus will be controlled at a temperature of  $90 \pm 2$  °F, and the maximum achievable relative humidity (RH) without occurrence of condensation (normally  $50\% \pm 10\%$  RH). The temperature and RH readings will be checked periodically with a calibrated meter. The test cell air will be drawn from the clean air manifold. The temperature and RH will be recorded in a computer file. Flow rates will be manually checked with a flow meter prior to test start. The TOP 8-2-501 specifies that differential pressure monitoring will be done, but this was not done for air-impermeable swatches.
4. The TOP test cell will be used. When assembling, the cell lugs will be tightened by hand to finger tight. The flow rate beneath each swatch will be 1 L/min, which will be controlled by a linear mass flow controller. The flows will be checked with a calibrated test meter before each test. Each test cell will be checked for leaks after assembly by connecting it to the vacuum source and checking that the inlet flow is the same as the outlet flow on the mass flow controller. If the flows don't match, the test cell will be disassembled, adjustments made, the test cell reassembled and flows rechecked.
5. The TOP 8-2-501 specifies that positive control and negative control swatches will be used, but positive controls will not be used due to budgetary and schedule limitations. The swatches will be preconditioned for at least 2 hr. Eighty-mil silicone will be used, one for each test (nine suit swatches, one negative control swatch and one silicone swatch).

6. Agents GB and HD will be used. The contamination density will be  $10 \text{ g/m}^2$  (8 each  $1 \text{ }\mu\text{L}$  HD droplets or 10 each  $1 \text{ }\mu\text{L}$  GB droplets). A robotic agent application system is not available. The agent will be applied using the click/touch method with a repeating dispenser.

7. Eleven swatches will be tested at once. MINICAMS™ with stream selection system will monitor vapor penetration with a 3-min cycle. There will be one clean air sampling



## **APPENDIX B**

### **AEROSOL SIMULANT TEST PROCEDURE**

To properly test suits with statistical significance, eight suit ensembles of each model were provided to the Mask Fit Test Facility for examination. Each ensemble was new and inspected as received. The suit ensembles include relevant accessory equipment such as respirators that were worn with the suits, gloves, boots, and any other equipment that is necessary for chemical agent use. The suit ensembles were run on at least 10 different subjects with at least 22 trials. The eight suits were reused to achieve the 22 or more trials. Sampling of suits was done at the neck and upper arm for each trial. The pre-operational exercises are designed to stress the suit, whereas the operational exercises are scenario based.

Exercise routine for all suits were as follows:

#### **Phase 1 (Pre-Operational)**

1. standing still, normal breathing
2. bending forward and touching toes
3. jogging in place
4. raising arms above head and looking upward
5. bending knees and squatting
6. crawling on hands and knees
7. torso twists with hands folded on chest
8. standing still, normal breathing

#### **Phase 2 (Operational)**

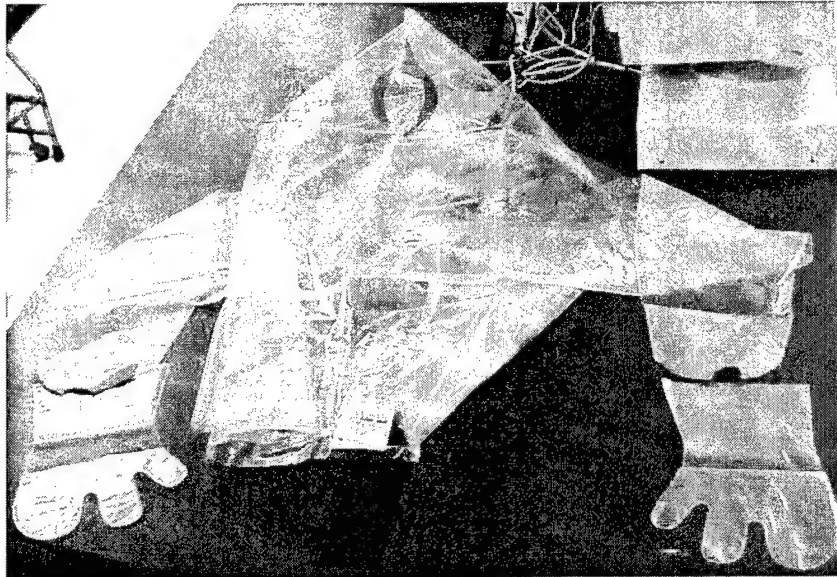
1. climb step ladder
2. move 3 lb boxes from table to floor
3. rest
4. roll walls and ceiling
5. bag clothes
6. rest
7. loosen bolts
8. move 3 lb boxes from floor to table

This PF test measured leakage into the suit by an aerosol, which can only occur through holes or open pathways. It cannot occur by permeation. A corn oil aerosol was used with a MMAD (Mass Median Aerodynamic Diameter) of 0.4 to 0.6 micron and a concentration of 20 to 40 mg/m<sup>3</sup>. Due to the instrumentation, the smallest PF value possible is 1, and the largest possible is 100,000.

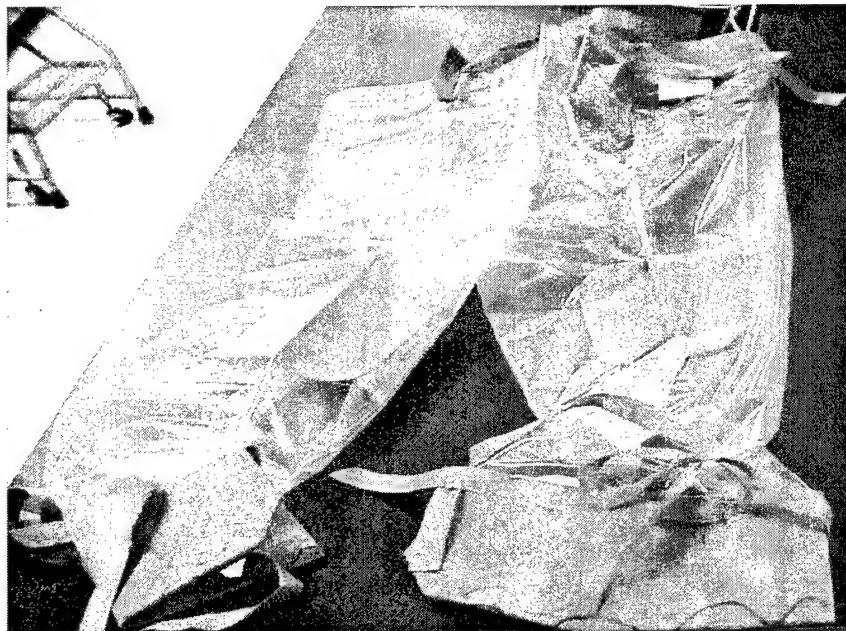
Note: The Phase 1 (Pre-Operational) exercises were performed for 1 min each for a total of 8 min. The Phase 2 (Operational) exercises were performed for 4 min each for a total of 32 min.

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**APPENDIX C**  
**TEST RESULTS AND PHOTOS**



**Figure C-1: ChemiCover Dress Jacket**



**Figure C-2: ChemiCover Dress Pants**

**Table C-1. Thickness Measurements**

ChemiCover Dress Material Swatch Thicknesses (inches)					
Date	Description	Thickness	Date	Description	Thickness
10-Apr-01	Suit Material (torso)	0.005	16 Jan 02	Suit Material (torso)	0.005
	Glove Material	0.005		Silicone, 2 layers	0.165
	Glove Material	0.005		Suit Material (torso)	0.005
	Glove Material	0.005		Suit Material (torso)	0.005
	Bootie Material	0.048		Suit Material (torso)	0.005
	Bootie Material	0.050		Suit/Hood Seam	0.018
	Bootie Material	0.065		Suit/Hood Seam	0.017
	Suit/Wrist Seam	0.011		Suit/Hood Seam	0.017
	Suit/Wrist Seam	0.011		Suit Seam (pants)	0.022
	Suit/Wrist Seam	0.012		Suit Seam (pants)	0.017
	Silicone	0.081		Suit Seam (pants)	0.030
11-Apr-01	Suit Material (torso)	0.005	24 Jan 02	Suit Material (torso)	0.005
	Crotch Seam	0.008		Silicone, 2 Layers	0.172
	Crotch Seam	0.010		Suit/Face Seam	0.009
	Crotch Seam	0.009		Suit/Face Seam	0.009
	Suit/Hood Seam	0.010		Suit/Face Seam	0.009
	Suit/Hood Seam	0.010		Bootie Material	0.093
	Suit/Hood Seam	0.009		Bootie Material	0.086
	Suit Material (torso)	0.005		Bootie Material	0.091
	Suit Material (torso)	0.005		Glove Material	0.005
	Suit Material (torso)	0.005		Glove Material	0.005
	Silicone	0.076		Glove Material	0.005
26-Apr-01	Suit Material (torso)	0.005			
	Crotch Seam	0.016			
	Glove Material	0.005			
	Silicone	0.083			

**Table C-2. Individual Swatch Data, First HD Test**

ChemiCover Dress C/91R Material vs. HD Liquid 10 g/m <sup>2</sup>																					
M <sub>r</sub> , Cumulative Permeation (ng/cm <sup>2</sup> ), 16 Jan 02																					
Controls				Suit Material (torso)					Suit/Hood Seam					Suit Seam (pants)							
Time (min)	Neg Cntrl	Time (min)	Silicone	Time (min)	1	Time (min)	2	Time (min)	3	Time (min)	1	Time (min)	2	Time (min)	3	Time (min)	1	Time (min)	2	Time (min)	3
1	0	3	0	16	0	21	0	26	0	33	0	38	0	43	206	51	0	56	3925	61	184
76	100	78	52	91	0	96	0	101	0	108	0	113	0	118	1159	126	0	131	14359	136	553
151	355	153	291	166	0	171	0	176	0	183	0	188	0	193	2153	201	0	206	24633	211	778
226	661	228	1084	241	0	246	0	251	0	258	0	263	0	268	2784	276	0	281	34828	286	927
301	930	303	3196	316	0	321	0	326	0	333	0	338	0	343	3220	351	0	356	45039	361	1059
376	1117	378	6929	391	0	396	0	401	0	408	0	413	0	418	3631	426	0	431	52987	436	1178
451	1186	453	11791	466	0	471	0	476	0	483	0	488	0	493	4099	501	0	506	56918	511	1291
526	1186	528	17011	541	0	546	0	551	0	558	0	563	0	568	4595	576	0	581	58636	586	1350
601	1186	603	21642	616	0	621	0	626	0	633	0	638	0	643	5057	651	0	656	59681	661	1350
676	1186	678	25531	691	0	696	0	701	0	708	0	713	0	718	5485	726	0	731	60476	736	1350
751	1186	753	28940	766	0	771	0	776	0	783	0	788	0	793	5878	801	0	806	61155	811	1350
826	1186	828	31906	841	0	846	0	851	0	858	0	863	0	868	6236	876	0	881	61769	886	1350
901	1186	903	34472	916	0	921	0	926	0	933	0	938	0	943	6556	951	0	956	62351	961	1350
976	1186	978	36650	991	0	996	0	1001	0	1008	0	1013	0	1018	6853	1026	0	1031	62904	1036	1350
1051	1186	1053	38549	1066	0	1071	0	1076	0	1083	0	1088	0	1093	7130	1101	0	1106	63432	1111	1350
1126	1186	1128	40193	1141	0	1146	0	1151	0	1158	0	1163	0	1168	7376	1176	0	1181	63947	1186	1350
1201	1186	1203	41617	1216	0	1221	0	1226	0	1233	0	1238	0	1243	7591	1251	0	1256	64444	1261	1350
1276	1186	1278	42868	1291	0	1296	0	1301	0	1308	0	1313	0	1318	7778	1326	0	1331	64918	1336	1350
1351	1186	1353	43961	1366	0	1371	0	1376	0	1383	0	1388	0	1393	7942	1401	0	1406	65370	1411	1350
1426	1186	1428	44947																		

Note 1: The negative control M<sub>r</sub>, cumulative permeation (ng/cm<sup>2</sup>) values were subtracted out as background.

Note 2: In all M<sub>r</sub> tables, zero (0) is equivalent to non-detectable (ND).

**Table C-3. Individual Swatch Data, Second HD Test**

ChemiCover Dress Material vs. HD Liquid 10 g/m <sup>2</sup> - Static Diffusion																					
M <sub>r</sub> , Cumulative Permeation (ng/cm <sup>2</sup> ), 24 Jan 02																					
Controls				Suit/Face Seam						Bootie Material						Glove Material					
Time (min.)	Neg Con	Time (min.)	Silicone	Time (min.)	1	Time (min.)	2	Time (min.)	3	Time (min.)	1	Time (min.)	2	Time (min.)	3	Time (min.)	1	Time (min.)	2	Time (min.)	3
2	0	5	0	20	175	26	38	32	718	41	78	47	0	53	0	62	0	68	0	74	0
92	0	95	152	110	2971	116	1992	122	4758	131	688	137	155	143	96	152	53	158	49	164	41
182	0	185	692	200	6984	206	5538	212	8802	221	1748	227	468	233	288	242	160	248	158	254	124
272	0	275	2373	290	11003	296	9093	302	12858	311	2942	317	752	323	459	332	250	338	269	344	233
362	0	365	5127	380	15026	386	12628	392	16917	401	3973	407	972	413	589	422	285	428	366	434	365
452	0	455	8330	470	19053	476	16166	482	20983	491	4980	497	1160	503	698	512	285	518	460	524	489
542	0	545	11865	560	23088	566	19807	572	25057	581	6201	588	1345	594	801	603	285	609	554	615	604
633	0	636	15440	651	27123	657	23280	663	29130	672	7600	678	1520	684	895	693	285	699	648	705	711
723	0	726	19004	741	31155	747	26521	753	33202	762	9078	768	1679	774	939	783	285	789	744	795	804
813	0	816	22568	831	35186	837	29457	843	37273	852	10586	858	1827	864	973	873	285	879	837	885	887
903	0	906	26131	921	39216	927	32061	933	41392	942	12141	948	1968	954	1039	963	285	969	924	975	965
993	0	996	29636	1011	43245	1017	34450	1023	45510	1032	13934	1038	2123	1044	1109	1053	285	1059	1006	1065	1052
1083	0	1086	32987	1101	47268	1107	36622	1113	49580	1122	16108	1128	2299	1134	1186	1143	285	1149	1081	1155	1154
1173	0	1176	36060	1191	51286	1197	38577	1203	53645	1212	18605	1218	2486	1224	1264	1233	285	1239	1156	1245	1303
1263	0	1266	38860	1281	55307	1287	40349	1293	57703	1302	21365	1308	2674	1314	1340	1323	285	1329	1232	1335	1500
1353	0	1356	41501	1371	59326	1377	41953	1383	61759	1392	24276	1398	2858	1404	1412	1413	285	1419	1306	1425	1718

Note 1: In all M<sub>r</sub> tables, zero (0) is equivalent to non-detectable (ND).

**Table C-4. Individual Swatch Data, First GB Test**

ChemiCover Dress C/91R Material vs. GB Liquid 10 g/m <sup>2</sup>																			
Mr, Cumulative Permeation (ng/cm <sup>2</sup> ), 10 April 01																			
Controls				Glove Material				Bootie Material					Suit/Wrist Seam						
Time (min)	Neg Cntrl	Time (min)	Silicone	Time (min)	2	Time (min)	3	Time (min)	1	Time (min)	2	Time (min)	3	Time (min)	1	Time (min)	2	Time (min)	3
1	0	52	73	4	0	10	0	16	0	22	0	28	0	34	0	40	1918	46	2587
76	0	127	487	79	0	85	0	91	0	97	0	103	0	109	5393	115	9296	121	13323
151	0	202	1066	154	0	160	0	166	0	172	0	178	0	184	14063	190	16935	196	24217
226	0	277	1608	229	0	235	0	241	0	247	0	253	0	259	18991	265	23126	271	32359
301	0	352	2149	304	0	310	0	316	0	322	0	328	0	334	21250	340	28450	346	37835
376	0	427	2868	379	0	385	0	391	0	397	0	403	0	409	21857	415	32061	421	40555
451	0	502	3606	454	0	460	0	466	0	472	0	478	0	484	21932	490	35059	496	42545
526	0	577	4179	529	0	535	0	541	0	547	0	553	0	559	22007	565	38989	571	44781
601	0	652	4741	604	0	610	0	616	0	622	0	628	0	634	22854	640	41998	646	47976
676	0	727	5328	679	0	685	0	691	0	697	0	703	0	709	23701	715	44789	721	50573
751	0	802	6095	754	0	760	0	766	0	772	0	778	0	784	23701	790	47892	796	52180
826	0	877	6866	829	0	835	0	841	0	847	0	853	0	859	23701	865	49723	871	53446
901	0	952	7495	904	0	910	0	916	0	922	0	928	0	934	24182	940	50490	946	55040
976	0	1027	8120	979	0	985	0	991	0	997	0	1003	0	1009	24664	1015	51329	1021	56666
1051	0			1054	0	1060	0	1066	0	1072	0	1078	82	1084	24664	1090	52334	1096	58033

Note 1: In all M<sub>r</sub> tables, zero (0) is equivalent to non-detectable (ND). Detection limit was 1.0 ng.

Note 2: Due to human error, the first glove swatch was not sampled.

Note 3: The test ended prematurely due to equipment malfunction.

**Table C-5. Individual Swatch Data, Second GB Test**

ChemiCover Dress C/91R Material vs. GB Liquid 10 g/m <sup>2</sup>																			
M <sub>r</sub> , Cumulative Permeation (ng/cm <sup>2</sup> ), 11 April 01																			
Controls				Crotch Seam				Suit/Hood Seam						Suit Material (torso)					
Time (min)	Neg Cntrl	Time (min)	Silicone	Time (min)	2	Time (min)	3	Time (min)	1	Time (min)	2	Time (min)	3	Time (min)	1	Time (min)	2	Time (min)	3
1	0	52	0	4	0	10	21	16	8	22	19	28	18	34	29	40	35	46	23
76	0	127	266	79	156	85	224	91	45	97	82	103	201	109	256	115	229	121	139
151	0	202	754	154	579	160	402	166	172	172	82	178	511	184	507	190	429	196	216
226	0	277	1222	229	1122	235	525	241	300	247	82	253	721	259	595	265	538	271	216
301	0	352	1749	304	1612	310	525	316	300	322	181	328	957	334	595	340	576	346	216
376	0	427	2322	379	1827	385	525	391	353	397	324	403	1264	409	595	415	576	421	216
451	0	502	2944	454	1953	460	525	466	407	472	369	478	1446	484	595	490	576	496	216
526	0	577	3629	529	2131	535	525	541	407	547	417	553	1644	559	595	565	576	571	216
601	0	653	4352	604	2183	610	525	616	407	622	520	629	1813	635	595	641	576	647	216
678	0	730	5105	681	2183	687	525	693	444	699	612	705	1900	711	595	717	576	724	216
754	0	806	5857	757	2265	764	525	770	550	776	695	782	2018	788	595	794	576	800	216
831	0	883	6601	834	2346	840	525	846	619	852	794	859	2160	865	595	871	576	877	216
908	0	960	7366	911	2346	917	525	923	619	929	846	935	2227	941	595	947	576	954	216
984	0	1036	8049	987	2346	993	571	1000	619	1006	900	1012	2279	1018	595	1024	576	1030	216
1061	0	1113	8473	1064	2387	1070	618	1076	672	1082	1013	1088	2383	1095	595	1101	576	1107	216

Note 1: In all M<sub>r</sub> tables, zero (0) is equivalent to non-detectable (ND). Detection limit was 1.0 ng.

Note 2: Due to human error, the first crotch seam swatch was not sampled.

Note 3: The test ended prematurely due to equipment malfunction.

**Table C-6. Individual Swatch Data, Third GB Test**

ChemiCover Dress Material vs. GB Liquid 10 g/m <sup>2</sup>							
M <sub>f</sub> , Cumulative Permeation (ng/cm <sup>2</sup> ), 26 April 01							
Time (min)	Neg Cntrl	Time (min)	Crotch Seam	Time (min)	Glove Mtl	Time (min)	Silicone
1	0	4	14	10	2	NR	NR
76	0	79	309	85	13	NR	NR
151	0	154	433	160	13	NR	NR
226	0	229	519	235	13	NR	NR
301	0	304	587	310	13	NR	NR
376	0	379	1582	385	35	NR	NR
451	0	454	3673	460	84	NR	NR
526	0	529	5939	535	138	NR	NR
601	0	604	8233	610	193	NR	NR
676	0	679	10508	685	245	NR	NR
751	0	754	12688	760	295	NR	NR
826	0	829	14729	835	343	NR	NR
901	0	904	16597	910	388	NR	NR
976	0	979	18323	985	431	NR	NR
1051	0	1054	19922	1060	471	NR	NR
1126	0	1129	21386	1135	508	NR	NR
1201	0	1204	22741	1210	540	NR	NR
1276	0	1279	24015	1285	567	NR	NR
1351	0	1354	25239	1360	589	NR	NR
1426	0	1429	26402	1435	608	NR	NR

Note 1: In all M<sub>f</sub> tables, zero (0) is equivalent to non-detectable (ND). Detection limit was 1.0 ng.

Note 2: Positive control data not reported (NR) because of possible flow controller malfunction.

**Table C-7. Weighted Average M<sub>f</sub>, HD**

ChemiCover Dress C/91R - January 16-29, 2002													
Time (min)	Glove Material	Time (min)	Bootie Material	Time (min)	Suit/Face Seam	Time (min)	Suit Seam (pants)	Time (min)	Suit/Hood Seam	Time (min)	Suit Material (torso)	Average Time (min)	Weighted Average M <sub>f</sub>
68	0	47	26	26	1657	56	1370	38	69	21	0	43	226
158	48	137	313	116	4588	131	4971	113	386	96	0	125	782
248	147	227	835	206	8460	206	8470	188	718	171	0	208	1404
338	250	317	1384	296	12338	281	11918	263	928	246	0	290	2019
428	339	407	1845	386	16212	356	15366	338	1073	321	0	373	2619
518	411	497	2279	476	20092	431	18055	413	1210	396	0	455	3140
609	481	588	2782	566	24008	506	19403	488	1366	471	0	538	3535
699	548	678	3338	657	27868	581	19995	563	1532	546	0	621	3858
789	611	768	3899	747	31650	656	20344	638	1686	621	0	703	4152
879	670	858	4462	837	35345	731	20609	713	1828	696	0	786	4433
969	725	948	5049	927	38929	806	20835	788	1959	771	0	868	4705
1059	781	1038	5722	1017	42425	881	21040	863	2079	846	0	951	4979
1149	840	1128	6531	1107	45845	956	21234	938	2185	921	0	1033	5262
1239	915	1218	7452	1197	49189	1031	21418	1013	2284	996	0	1116	5552
1329	1006	1308	8459	1287	52472	1106	21594	1088	2377	1071	0	1198	5848
1419	1103	1398	9515	1377	50639	1181	21766	1163	2459	1146	0	1281	5893

Note 1: The time given for each sampling area is the average of the elapsed times for the three swatches tested per sampling area.

Note 2: The avg. time is the sum of the times given for each sampling area divided by the number of sampling areas.

Note 3: Weighted average M<sub>f</sub> = 0.6(suit torso material M<sub>f</sub>) + 0.1(glove material M<sub>f</sub>) + 0.1 (suit pants seam M<sub>f</sub>) + 0.05(suit/hood seam M<sub>f</sub>) + 0.1(bootie material M<sub>f</sub>) + 0.05(suit/face seam M<sub>f</sub>).



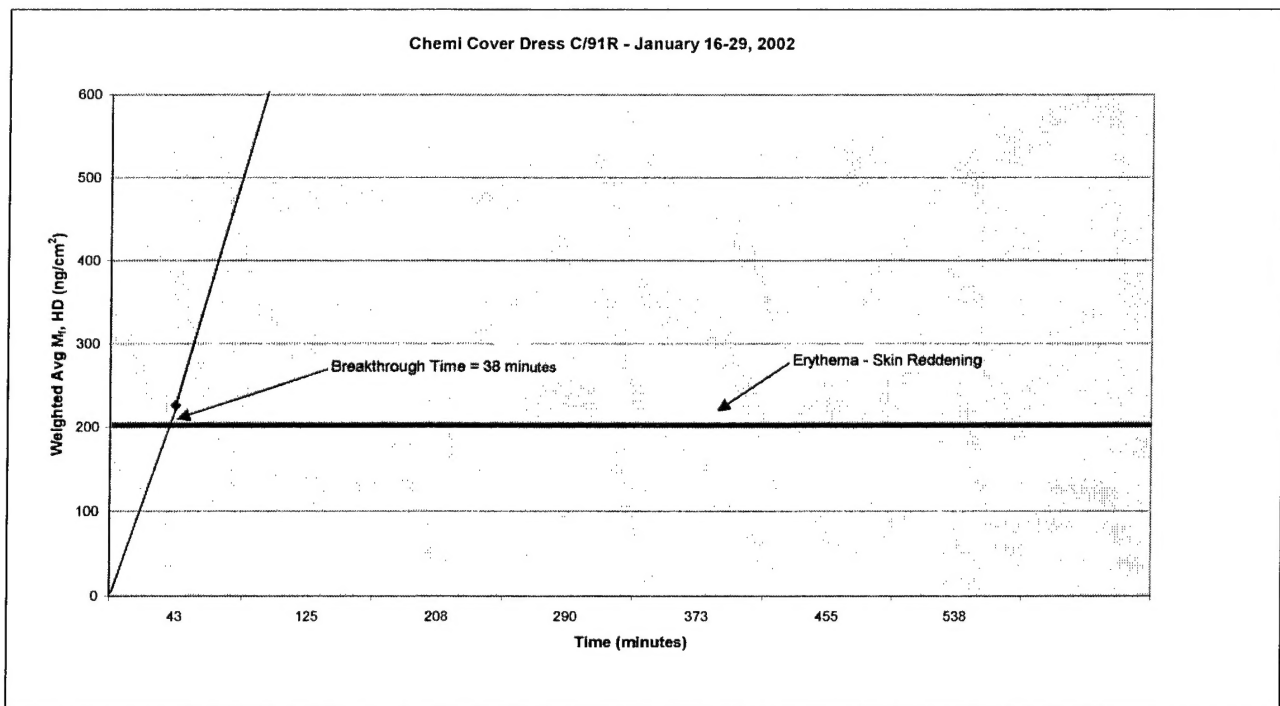
**Table C-8. Weighted Average  $M_f$ , GB**

ChemiCover Dress C/91R - April 10-26, 2001													
Time (min)	Glove Material	Time (min)	Bootie Material	Time (min)	Suit/Wrist Seam	Time (min)	Crotch Seam	Time (min)	Suit/Hood Seam	Time (min)	Suit Material (torso)	Average Time (min)	Weighted Average $M_f$
8	1	22	0	40	1502	6	11	22	15	40	29	23	94
83	4	97	0	115	9338	81	230	97	109	115	208	98	620
158	4	172	0	190	18405	156	471	172	255	190	384	173	1211
233	4	247	0	265	24825	231	722	247	368	265	450	248	1602
308	4	322	0	340	29178	306	908	322	479	340	462	323	1852
383	12	397	0	415	31491	381	1312	397	647	415	462	398	2017
458	28	472	0	490	33178	456	2050	472	741	490	462	473	2181
533	46	547	0	565	35259	531	2865	547	823	565	462	548	2373
608	64	622	0	640	37609	606	3647	622	913	641	462	623	2575
683	82	697	0	715	39688	682	4405	699	985	717	462	699	2760
758	98	772	0	790	41258	758	5159	776	1088	794	462	775	2920
833	114	847	0	865	42290	834	5867	852	1191	871	462	850	3050
908	129	922	0	940	43237	911	6489	929	1231	947	462	926	3163
983	144	997	0	1015	44220	986	7080	1006	1266	1024	462	1002	3274
1058	157	1072	0	1090	45010	1063	7642	1082	1356	1101	462	1078	3376

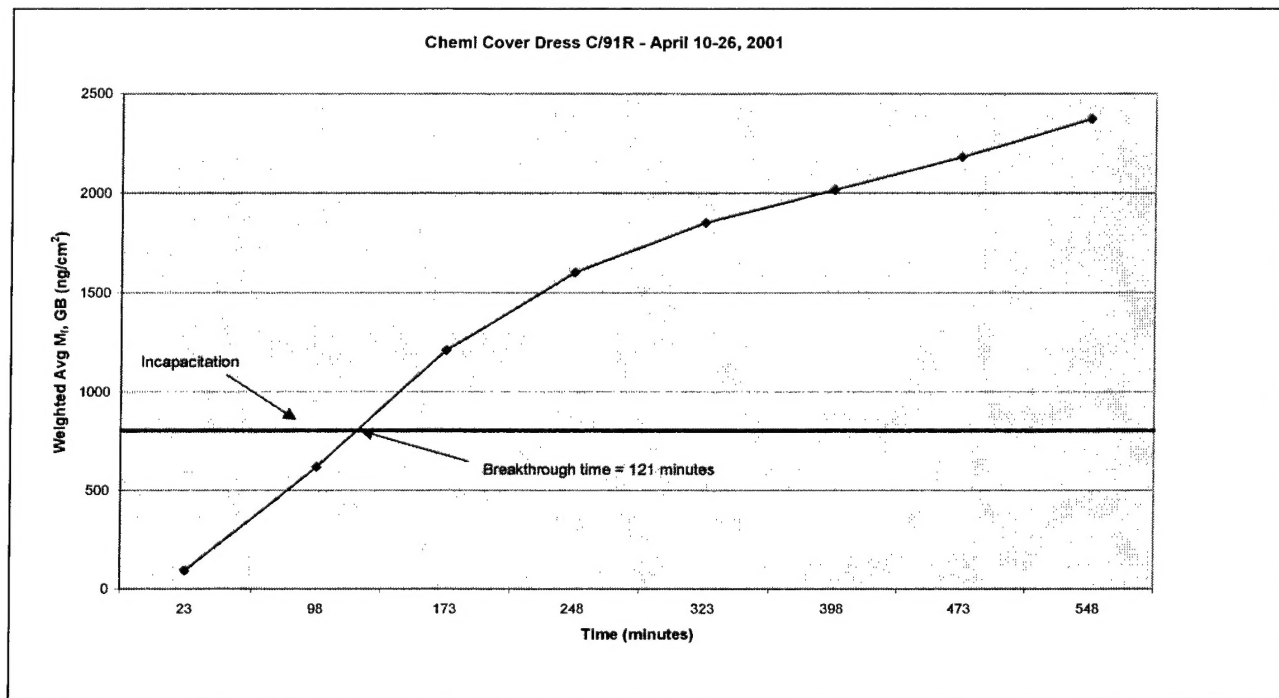
Note 1: The time given for each sampling area is the average of the elapsed times for the three swatches tested per sampling area.

Note 2: The avg. time is the sum of the times given for each sampling area divided by the number of sampling areas.

Note 3: Weighted average  $M_f = 0.6(\text{suit torso material } M_f) + 0.1(\text{glove material } M_f) + 0.1(\text{suit pants seam } M_f) + 0.05(\text{suit/hood seam } M_f) + 0.1(\text{bootie material } M_f) + 0.05(\text{suit/face seam } M_f)$ .



**Figure C-3: Weighted Average HD Permeation**



**Figure C-4: Weighted Average GB Permeation**

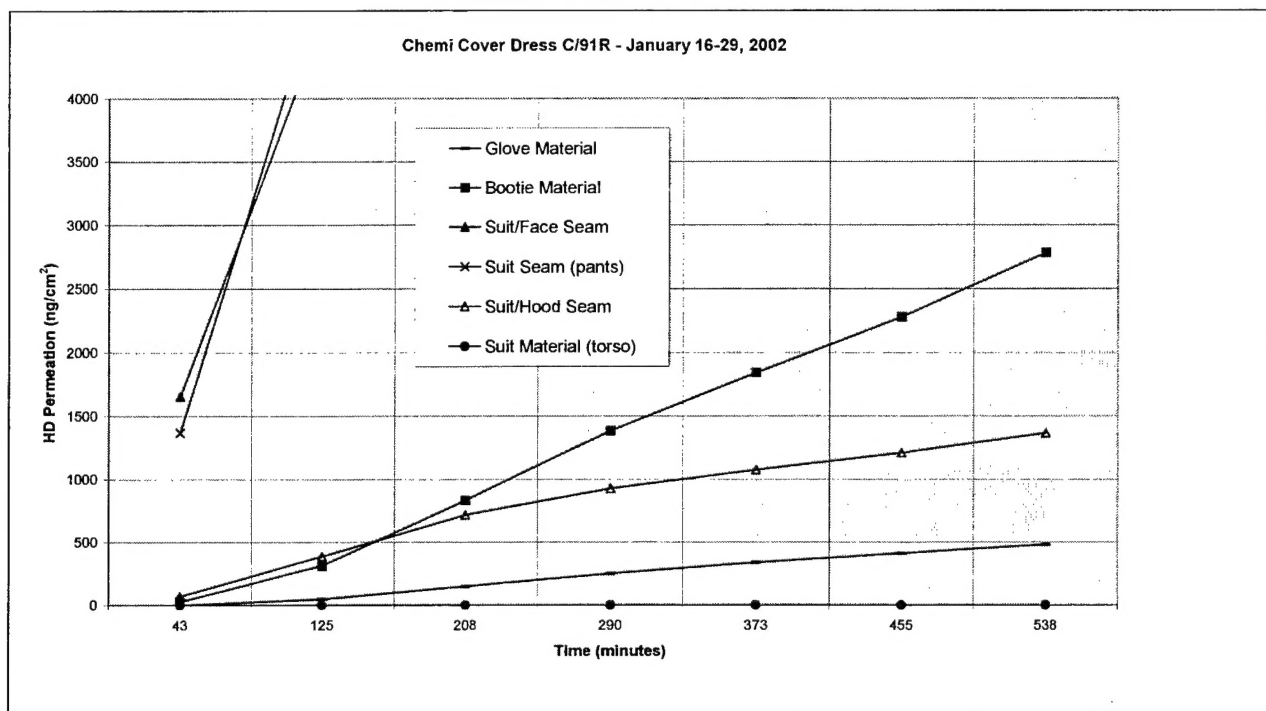


Figure C-5: HD Permeation by Sampling Area

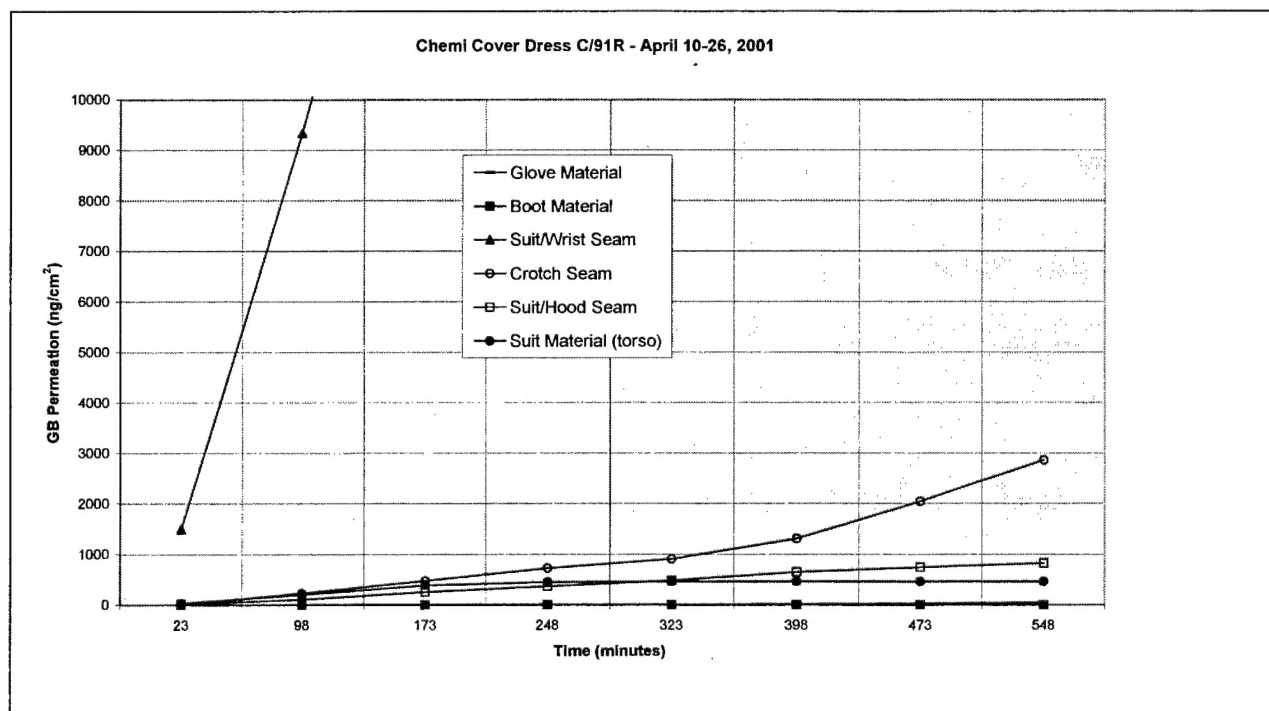


Figure C-6: GB Permeation by Sampling Area

**Table C-9. System Test (Aerosol Simulant) Results**

PF	Visor Region and Upper Arm, Combined					
	Pre-Operational Exercises			Operational Exercises		
	Frequency	Cumulative Rate, Percent	Cumulative Pass Rate, Percent	Frequency	Cumulative Rate, Percent	Cumulative Pass Rate, Percent
0	0	0.00	100.00	Not Tested	Not Tested	Not Tested
10	31	96.88	3.13	Not Tested	Not Tested	Not Tested
20	1	100.00	0.00	Not Tested	Not Tested	Not Tested
50	0	100.00	0.0	Not Tested	Not Tested	Not Tested
100	0	100.00	0.00	Not Tested	Not Tested	Not Tested
500	0	100.00	0.00	Not Tested	Not Tested	Not Tested
1000	0	100.00	0.00	Not Tested	Not Tested	Not Tested
1667	0	100.00	0.00	Not Tested	Not Tested	Not Tested
2000	0	100.00	0.00	Not Tested	Not Tested	Not Tested
5000	0	100.00	0.00	Not Tested	Not Tested	Not Tested
6667	0	100.00	0.00	Not Tested	Not Tested	Not Tested
10000	0	100.00	0.00	Not Tested	Not Tested	Not Tested
20000	0	100.00	0.00	Not Tested	Not Tested	Not Tested
50000	0	100.00	0.00	Not Tested	Not Tested	Not Tested
100000	0	100.00	0.00	Not Tested	Not Tested	Not Tested
No. of Trials	32					